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Performance Simulation and Verification of Vat Photopolymerization Based, Additively Manufactured Injection Molding Inserts with Micro-Features

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Abstract. Injection molding soft tooling inserts manufactured additively with vat photopolymerization represent a valid technology for prototyping and pilot production of polymer parts. However, a significant drawback is the low heat conductivity of photopolymers influencing cycle time and part quality. In this research, the thermal performance of a 20x20x2.7 mm^3 injection molding insert was simulated. A thermal camera was used to assess the quality and accuracy of the simulation. Both, simulation and measurements showed that the temperature cycle during injection molding becomes stationary within 3 to 5 cycles. After 2800 injection molding cycles, the experiment was stopped and the insert was still intact.

Keywords: Additive manufacturing, Micro injection molding, Soft tooling, Simulation

1 Introduction

Soft tooling injection molding inserts manufactured with vat photopolymerization enable fast and cost effective prototyping and pilot production. Available materials generally enable either high accuracy or have high resitance to heat [1]. The lifetime of vat photopolymerization soft tooling inserts has been reported mainly in the two- to three-digits cycle range ([5],[3]). However, [2] reported a lifetime of more than 2500 cycles when injection molding polyethylene low-density with carbon fiber-reinforced soft tooling inserts. The suitability of additive manufacturing for the production of inserts for micro injection molding has been demonstrated, e.g. in [3] and [4]. This research benchmarks the thermal performance of vat photopolymerization soft tooling injection molding inserts against conventional injection molding with a brass insert.

2 Materials and Methods

2.1 Design of Test Part

The test part consisted of a cuboid structure comprising two heart shaped structures (Figure 1). The cuboids outer dimensions were 20x20x2.7 mm^3. In addition, two cuboid structures with micro cylinders (800 µm diameter, 300 µm high) were present.

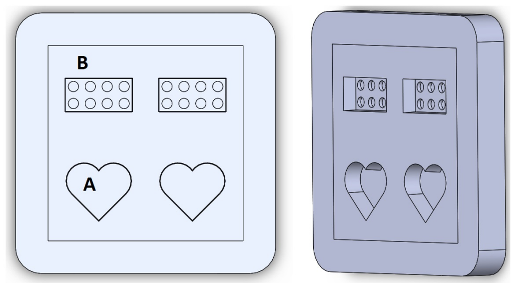

Fig. 1. CAD model of test part. Areas A and B are marked with letters.

2.2 Tooling

The inserts were manufactured in SOMOS®perform using a stereolithography vat photopolymerization printer.

2.3 Simulation

Five injection molding cycles were simulated in COMSOL Multiphysics®. One injection molding cycle consisted of the following periods resulting in a total cycle time of 20 seconds.

- Injection and packing: 8.5 seconds
- Mold opening, cooling down, and mold closing: 11.5 seconds

The material properties of the photopolymer were set to 0.167 W/mK for the thermal conductivity, 1100 kg/m^3 for the density, and 1400 J/kgK for the heat capacity.

2.4 Injection Molding and Thermal Imaging

An Engel®injection molding machine was used to injection mold acrylonitrile butadiene styrene (ABS) with an injection pressure of 300 bar.

A thermal camera (FLIR®A655sc) was installed and driven down from above the machine to take thermal images when the mold was open. About five seconds passed from when the mold started opening to when the camera could start taking images. The images were analyzed with the camera manufacturer's software requiring the emissivity of the photopolymer. As a consequence, the emissivity was calibrated and set to 0.95.
Two different temperature measurements were conducted:

- An image series over 100 injection molding cycles (one image taken after each cycle). The first five cycles are presented in figure 2.
- A video capture of the natural cooling process after one injection molding cycle (2 frames per second, figure 3)

2.5 Metrological Assessment

The injection molded parts as well as the inserts were analyzed with a scanning electron microscope (SEM) as well as a laser scanning microscope (OLYMPUS Lext®). SEM pictures were taken before injection molding, after about 100 shots and after 2800 shots.

3 Results

3.1 Comparison of Thermal Simulations and Temperature Measurements

Figure 3 shows that the measured values (starting 5 seconds after mold opening) are matching the simulated values closely. Consequently, it can be assumed that the simulation presents a plausible calculation of the temperature development over the whole injection molding cycle, providing valuable information for future research and investigations on thermal ageing of soft tooling inserts.

3.2 Temperature Development

The temperature cycles became stationary within three to five cycles in both simulations and measurements.
The maximum temperature present on the insert was found to be below 410 K.
The high thermal inertia of the photopolymer became visible in figure 2 since the photopolymer insert was still heating up when the brass insert already started cooling down.
Figure 4 shows the temperature development in the insert symmetry plane as well as in a local symmetry plane in the heart / cuboid / cylinder region of the insert.

3.3 Insert Life Time

A soft tooling micro injection molding insert was used successfully for 2800 shots of ABS. The insert was still intact after the experiment which demonstrates a significant improvement when compared to, e.g., [2].

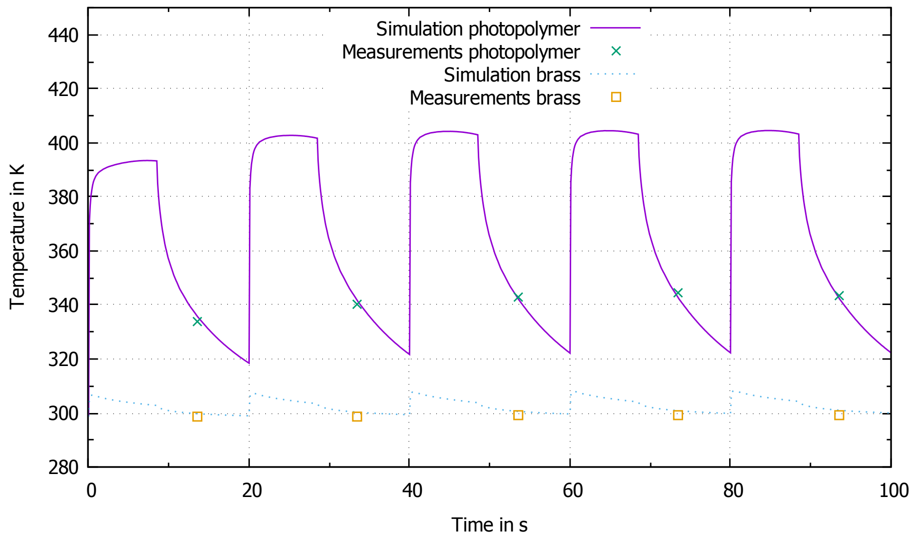

Fig. 2. Simulated and measured temperature development over the first five injection molding cycles.

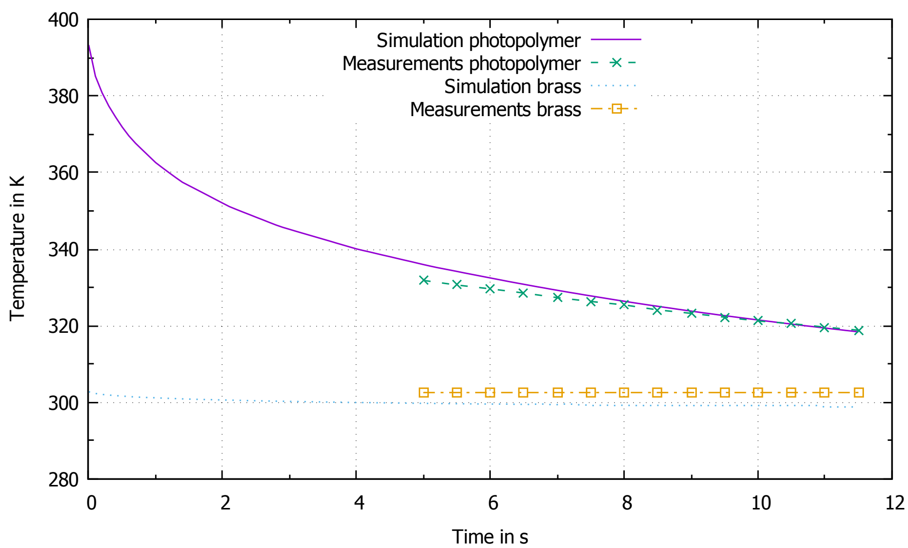

Fig. 3. Simulated and measured temperature development during the first injection molding cycle after mold opening.

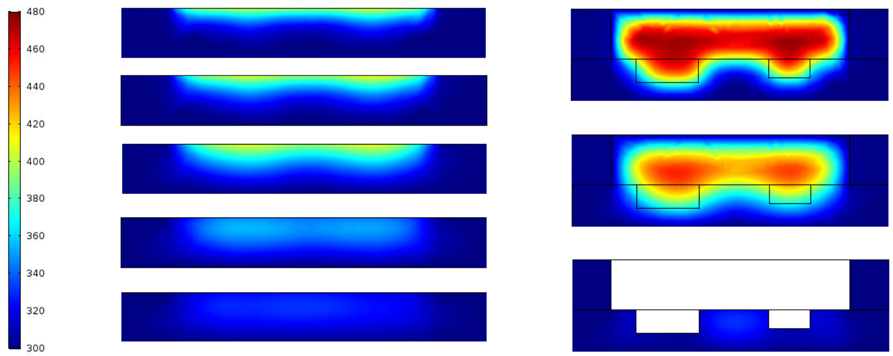

Fig. 4. Temperature development in the insert symmetry plane (left column: after 3, 5, 8.5, 12, and 17 seconds from top to bottom) and in a local symmetry plane in the heart / cuboid / cylinder region of the insert (right column: after 3, 8.5, and 17 seconds from top to bottom). In the right column, the ABS injection molded part is present during the injection and packing phase (8.5 seconds).

3.4 Inserts Before and After Injection Molding

Figures 5, 6, and 7 show SEM images of the inserts before and after injection molding. On the photopolymer insert, no insert degradation or wear was detected during metrological analysis with a laser scanning microscope after 2800 injection molding cycles.

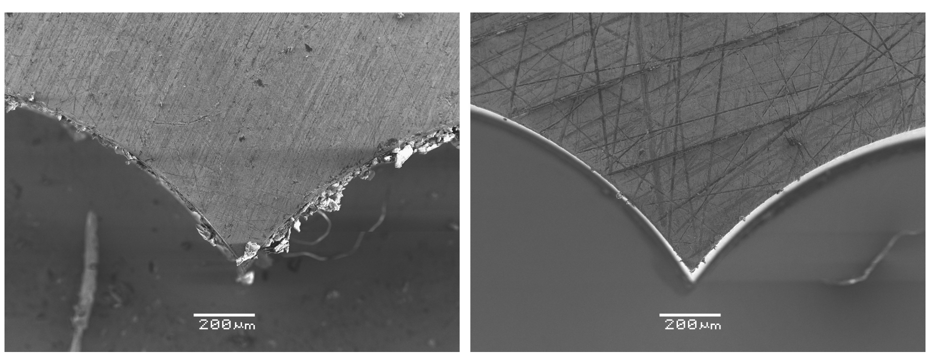

Fig. 5. Area A of a brass insert before injection molding (left) and after about 100 shots ABS (right).

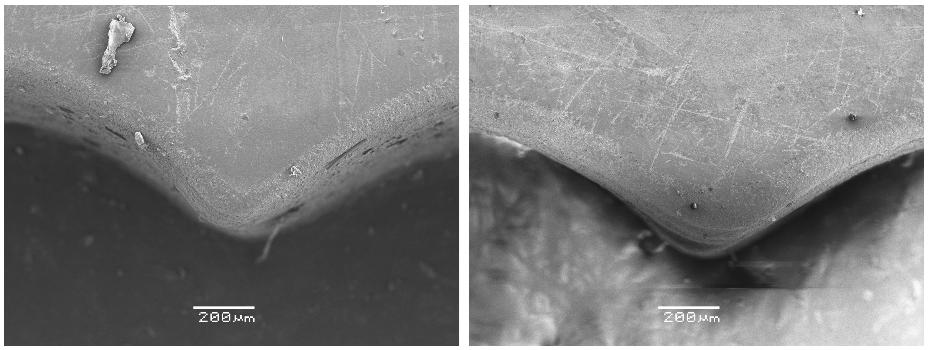

Fig. 6. Area A of a photopolymer insert before injection molding (left) and after about 100 shots (right).

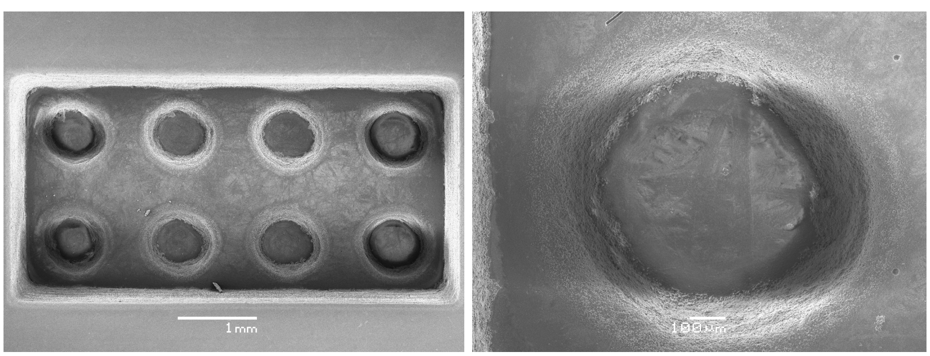

Fig. 7. Area B of a photopolymer insert after 2800 shots ABS.

4 Conclusions

– The thermal simulation was found to be an accurate tool for the investigation of the temperature development in the injection molding inserts.
– The very low thermal conductivity of the photopolymer compared to brass (ca. 650x smaller) leads to a significantly longer injection molding cycle time (the cooling time was set to 11.5 s for an insert geometry of 20x20x2.7 mm^3).
– After 2800 injection molding cycles with ABS, the photopolymer insert was still intact which represents a significant increase in lifetime when compared to numbers reported in, e.g., [1] or [2]. No insert wearing was detected in a metrological analysis with an SEM and laser scanning microscopy.

Suggestions for Future Research: It is suggested to investigate

– thermal simulations with a larger insert geometry,
– model fiber-reinforced and/or coated injection molding inserts to quantify the influence of these modifications on cycle time and insert lifetime,
– the thermal ageing process to increase the predictability and reliability of vat photopolymerization soft tooling inserts.

5 Acknowledgements

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